



ontario hydro research division

To: Mr. J.L. McFarlane
Resident Engineer
Darlington GS

Attn: Mr. W. Cushing/J. Aitken

DARLINGTON GS
EVALUATION OF WAITING PERIOD
FOR CONCRETE MONOLITHS

P.K. Mukherjee

The Darlington GS construction specification requires that a filler monolith be placed only after the adjacent monoliths have cooled to within 6°C of the ambient temperature. This is to minimize thermal cracking. Sometimes this requirement results in a long waiting period. A question was raised whether or not the requirement of a 6°C differential could be raised to a higher value, thus saving in construction time. A limited field study was initiated to determine the effect on the concrete of changing the placing criterion from 6°C to 12°C. This report describes observations made on a few placements. No adverse effect was noted; however, further field and laboratory studies are required to investigate various parameters such as size, shape and temperature. Recommendations for a change in the specification can only be made after completion and evaluation of the additional studies identified in this report.

1.0 INTRODUCTION

In order to reduce thermal cracking, construction specification requires that a filler monolith* should be placed only after the adjacent monoliths have cooled to within 6°C of the ambient temperature/1/. This at times results in long waiting periods. Based on the results of limited laboratory and field studies/2,3/, it was decided to try increasing the temperature differential to 12°C at non-critical locations and to examine the concrete for thermal cracking that may develop on the concrete surface.

*Monolith refers to large size concrete placements, the least dimension being one meter or greater.

job	file	date	report no.
42-147-450	842.622DAR	November 19, 1987	87-56-K

The objective was to choose as many different sizes and shapes of monoliths as possible and monitor the temperature and possible crack formation in both the filler and the adjacent monoliths. This report describes the results of this monitoring.

2.0 FIELD OBSERVATIONS

A number of sections were instrumented during the 1984 to 1986 construction period. However, because of other constraints during construction activities, the 12°C target temperature could not be achieved in all cases. Data from only three out of the eight sections instrumented were valid for the evaluation under the present context. Two of these sections were walls and one was a slab of the reactor buildings.

The following are the locations of these sections:

- (a) Wall: Monolith #423, #424, and #401 (Unit 1), #424 being the filler;
- (b) Wall: Monolith #450, #451, and #452 (Unit 2), #451 being the filler;
- (c) Slab: Monolith #233, #234, and #235 (Unit 1), #234 being the filler.

The shape and location of the monoliths are shown in Figure 1. The thickness of the wall and slab sections was 2.4 m and 1.8 m, respectively. In both instances the length of the filler monoliths was about 4.5 meters and that of the adjacent monoliths was about 8 meters. The concrete was proportioned according to Darlington GS Mix Code-444, except for Monoliths #450 and #451 where Mix Codes-544 and 543 were used, respectively. The proportions for each mix code are given in Table 1. The properties of the fresh concrete and the compressive strengths of standard moist cured test cylinders from these sections are given in Table 2.

The temperature at the centre and other locations of one of the adjacent monoliths in each section was monitored (see Tables 3 to 5). The filler monolith was placed when the adjacent monoliths had cooled to about 12°C above the ambient temperature. The temperatures of the filler and the adjacent monoliths were monitored until all the monoliths had cooled to the ambient temperature. The change in the temperature with time of centre points of the monoliths is shown in Figures 2, 3 and 4. It may be noted that the temperature differential (ΔT) was either slightly higher (16°C) or lower (10°C) than the target temperature of 12°C. No further evaluation of the remaining temperature data was made at this time.

The monoliths were visually examined after cooling and no cracks were noticed on the surface.

3.0 REMARKS

- 3.1 Two sizes (2.4 m and 1.8 m) and shapes (wall and slab) of structural elements were studied. The placing temperature of the concrete was between 10°C and 13°C and the average ambient temperature was between 12°C and 15°C. Also, three classes of concrete were used with the cement content ranging from 270 to 320 kg/m³. In all cases Type 40 cement was used.

- 3.2 Only a limited number of monoliths were monitored to determine the effect of changing the placing temperature criterion from 6°C to 12°C for the filler monoliths. No cracks were noticed in any of the monoliths examined.

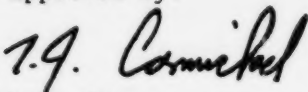
4.0 RECOMMENDATIONS

- 4.1 The maximum size of the monoliths that can be placed safely without cracking should be established. This could be determined initially from theoretical considerations. The theoretical analyses will require data on the changes in the early age properties such as tensile strain capacity, coefficient of thermal expansion and creep of various types of concrete. This portion of the study should be carried out in consultation with the Civil Design Department.
- 4.2 The placing and ambient temperatures along with the size and shape of monoliths are the major factors controlling the early age thermal cracking. Therefore, further field study is recommended to include higher placing and lower ambient temperatures for monoliths of different configurations and sizes.
- 4.3 Any recommendations for changes in the placing criterion (ie, 6°C to 12°C) can be made only after an evaluation of the data from the activities proposed in Items 4.1 and 4.2 above.

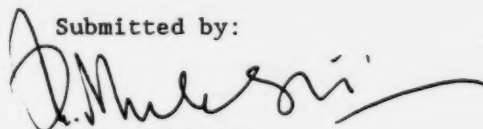
5.0 ACKNOWLEDGMENT

The work related to data analyses and computer graphics was carried out by Messrs. E.J. McColm and D. Aita.

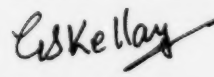
Approved by:


T.W. Klym
Manager
Civil Research Department

Submitted by:


P.K. Mukherjee
Senior Engineer
Concrete Technology Section

Reviewed by:


G.S. Kellay
Supervising Engineer
Concrete Technology Section

PKM:mao

REFERENCES

1. Darlington GS Construction Specification, "Time Intervals for Adjacent Concrete Pours," Refer to Clause 4.4.7.
2. Ontario Hydro Research Division Report No. 83-358-H dated August 24, 1983.
3. Ontario Hydro Research Division Report No. 83-542-H dated January 25, 1984.

TABLE 1
Darlington GS
Mix Proportions for Various Mix Codes

Materials	Mix Proportions (kg/m ³)		
	Mix Code		
	#444	#544	#543
Type 40 Cement	270	320	310
Fly Ash	14	Nil	Nil
Sand	840	748	815
40 mm Stone	560	600	Nil
20 mm Stone	390	410	760
14 mm Stone	160	180	330
Water/Cement Ratio	0.45	0.43	0.43
Admixture PDA 25XL	708 ml/m ³	838 ml/m ³	775 ml/m ³
Air-Ent Admixture	180 ml/m ³	240 ml/m ³	180 ml/m ³

TABLE 2
Darlington GS
Properties of Concrete for Various Monoliths

Properties of Concrete		Monoliths Numbers								
		423	424	401	450	451	452	233	234	235
Density:	kg/m ³	2369	2401	2369	2365	2280	2350	2411	2382	2335
Slump:	mm	80	70	90	80	140*	80	70	70	110
Air:	%	4.5	3.1	6.0	4.0	6.5	4.2	3.5	4.4	5.8
Temperature:	°C	11	12	10	12	12	10	13	12	10
Compressive Strength										
7-day:	MPa	15.9	17.5	15.2	23.8	20.1	-	17.4	20.0	14.4
28-day:	MPa	28.1	34.2	24.8	34.4	31.1	-	26.7	29.3	20.4

*Superplasticized Concrete

TABLE 3
DARLINGTON GS
TEMPERATURE RECORD OF MONOLITHS #423 AND #424
(SEE FIGURE 1 FOR THERMOCOUPLE LOCATION)

ELAPSED TIME (hr)	THERMOCOUPLE			READINGS (°C)			AMB. TEMP. °C	REMARKS
	POUR #423			POUR #424				
	TC#1	TC#2	TC#3	TC#1	TC#2	TC#3		
0	11	11	11				11	Placing temperature of
3	27	15	16					concrete in pour #423.
17	25	26	25					
24	28	30	29					
37	30	34	34					
50	30	36	36					
62	27	37	38					
74	25	37	39					
87	22	36	39				9	
109	22	34	38					
159	21	30	35					
190	21	29	33				15	
209				12	12	12		Placing temperature of
211	22	28	31	16	16	16	15	concrete in pour #424.
229	25	28	30	26	28	30	20	
244	27	27	30	27	34	34	18	
254	28	27	29	28	32	36	18	
262	29	27	29	28	32	37	18	
280	30	28	28	28	32	36	20	
325	33	30	27	29	32	38	20	
351	32	29	27	28	30	36	8	
373	32	29	27	27	30	36	8	
403	32	29	26	27	29	34		
423	32	29	25	26	28	34		
449	30	27	23	24	26	32		
497	32	30	25	25	26	32		
521	31	29	25	25	26	31		

TABLE 4
DARLINGTON GS
TEMPERATURE RECORD OF MONOLITHS #450 AND #451
(SEE FIGURE 1 FOR THERMOCOUPLE LOCATION)

ELAPSED	THERMOCOUPLE READINGS (°C)				AMB.	REMARKS
TIME (hr)	POUR #449(450)		POUR #451		TEMP. (°C)	
	TC#1	TC#2	TC#1	TC#2		
0	12	11			8	Placing temperature of concrete in pour #450.
12	21	20			10	
26	30	25			9	
38	33	27			14	
48	38	27			13	
61	41	28			10	
76	42	27			10	
113	41	22			15	
191	36	17			10	
217	34	17			10	
243	32	16			10	
324	28	15			10	
347	27	13			9	
362	26	11	12	12	9	Placing temperature of concrete in pour #451.
378	25	18	24	19	9	
385	24	20	30	25	10	
396	24	22	34	26	10	
410	23	23	36	26	13	
447	21	25	37	27	10	
517	22	22			11	
550	18	23	29	22	10	
572	16	22	28	21	13	
588	17	21	26	21	10	
666	17	17	19	19	10	
720	15	16	18	16	12	

TABLE 5
DARLINGTON GS
TEMPERATURE RECORD OF MONOLITHS #233 AND #234
(SEE FIGURE 1 FOR THERMOCOUPLE LOCATION)

ELAPSED TIME (hr)	THERMOCOUPLE			READINGS (°C)			AMB. TEMP. (°C)	REMARKS
	POUR #233			POUR #234				
	TC#1	TC#2	TC#3&4	TC#1	TC#2	TC#3&4		
0	13	13	13					Placing temperature of
43	33	36	35					concrete in pour # 233.
50	37	37	36					
68	30	37	37					
69								
92	27	35	35				8	
140	21	21	30				8	
151	20	31	30				8	
166	19	29	27				13	
213	17	26	25				12	
224	16	25	24				18	
232	16	26	24				14	
237	16	25	25				14	
256	15	24	22				15	
269	15	22	23				7	
280	15	22	22	12	12	12	12	Placing temperature of
304	17	21	21	23	25	24	16	concrete in pour # 234.
317	19	20	22	25	30	27	15	
322	19	20	20	26	32	28	17	
335	19	20	20	27	35	28	20	
395	21	20	18	27	36	28		
413	21	19	18	26	34	27		
435				25	33	22		
440	22	20	19	25	32	24	12	
442	21	20	20	25	32	24	11	
467				24	30	22		
476				23	30			
487				23	29	24		
501				22	28	22		
573				18	21	17		
643				16	20	16		
740				12	12	11		

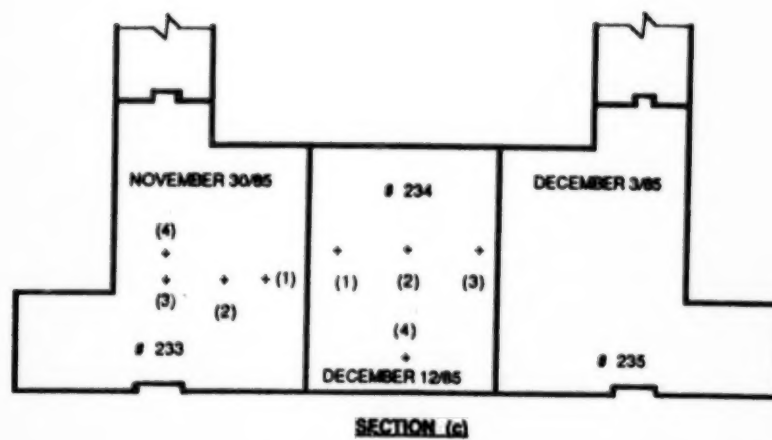
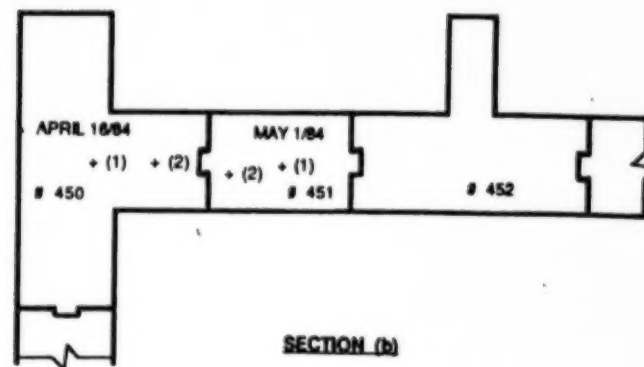
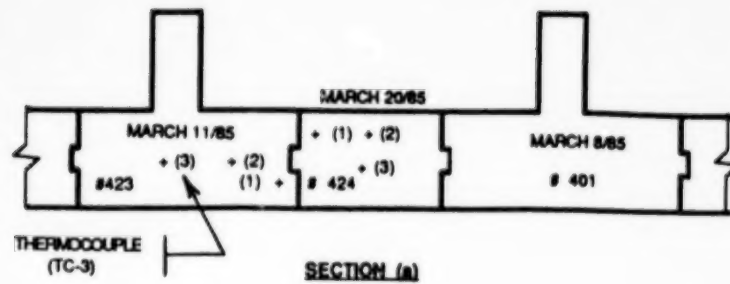


FIGURE 1
DARLINGTON GS
 APPROXIMATE SHAPE OF MONOLITHS AND LOCATIONS OF
 THERMOCOUPLES FOR TEMPERATURE MONITORING

DARLINGTON GS THERMOCOUPLE READINGS MONOLITHS #423 AND #424

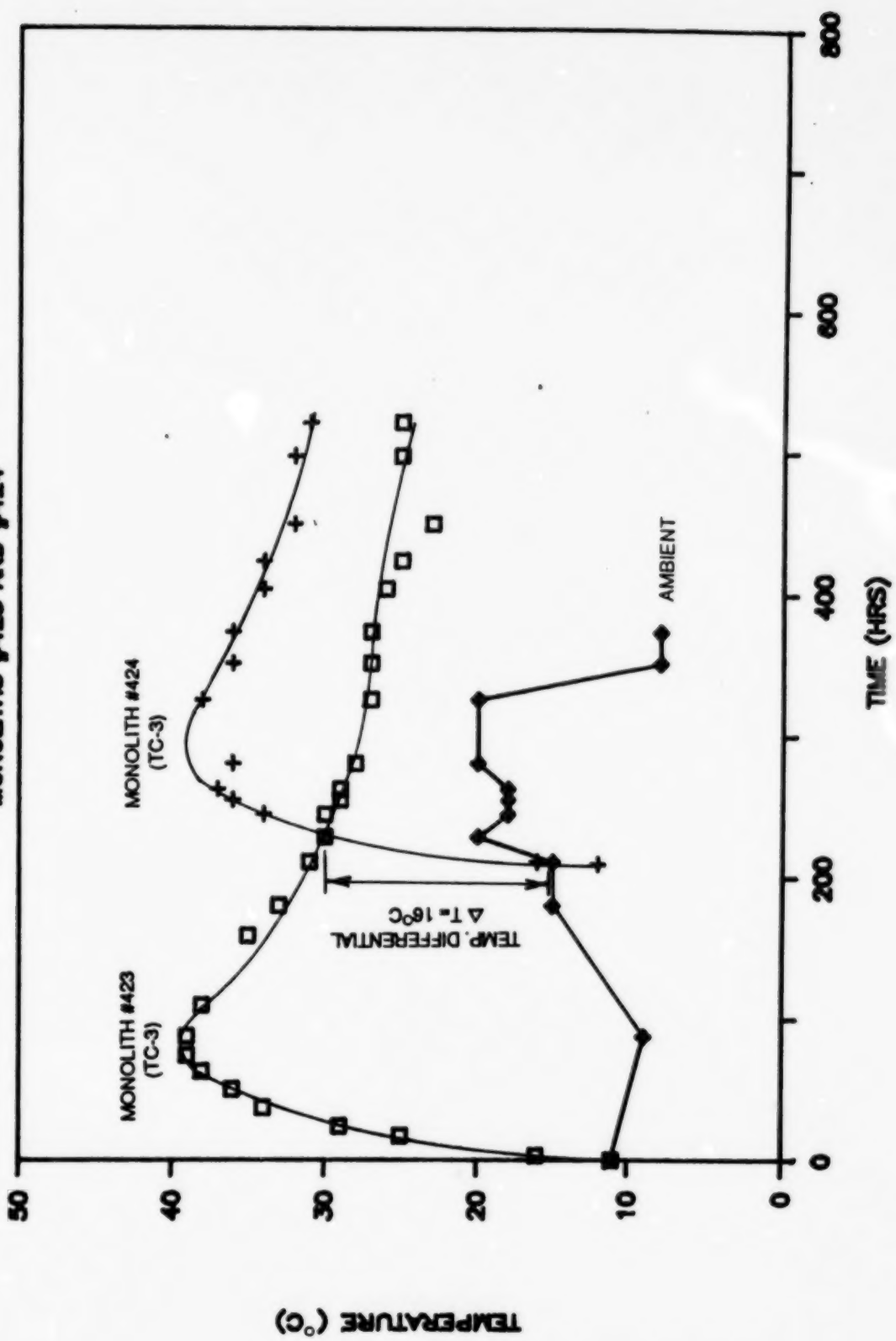


FIGURE 2

DARLINGTON GS THERMOCOUPLE READINGS MONOLITHS #450 AND #451

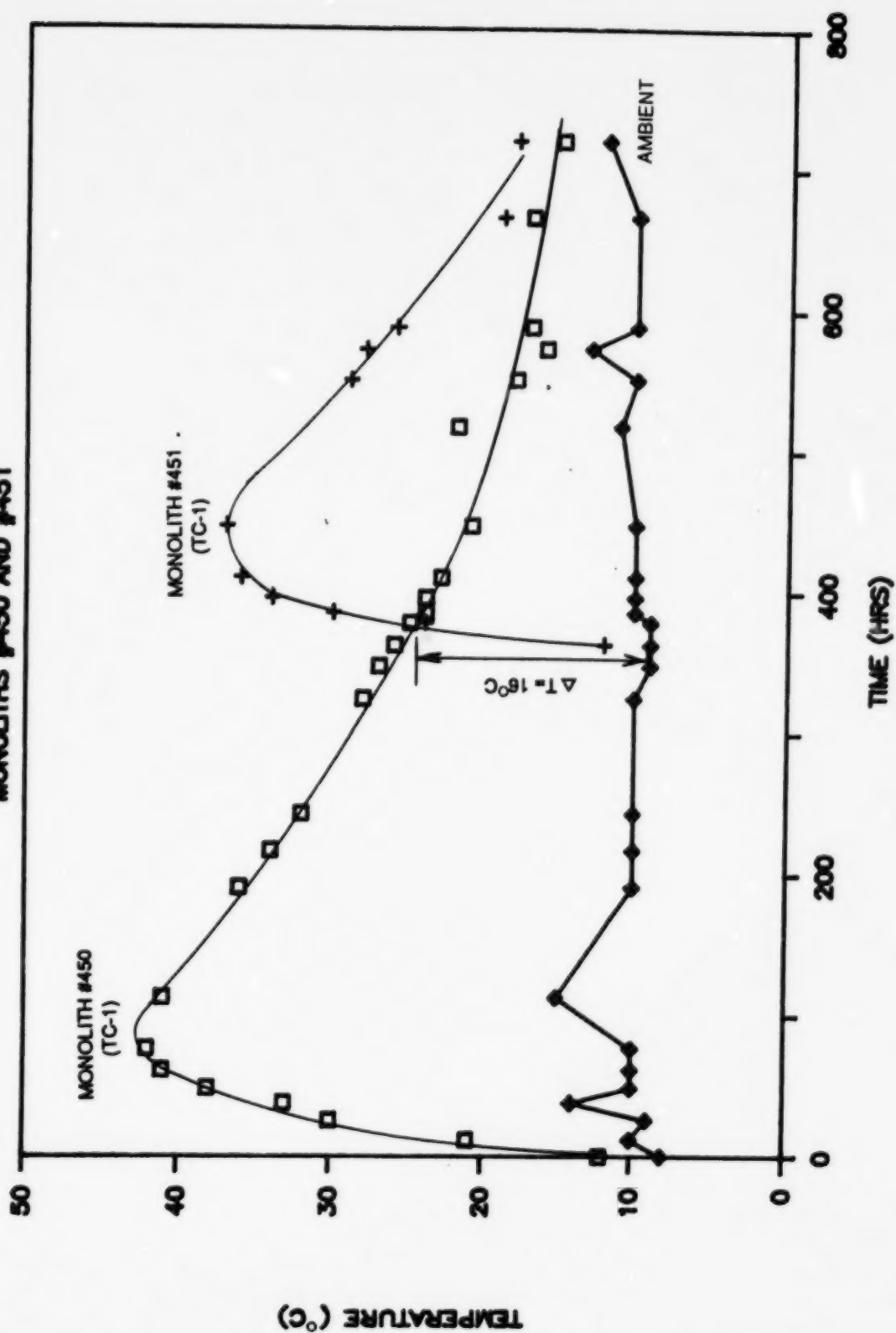


FIGURE 3

DARLINGTON GS THERMOCOUPLE READINGS MONOLITHS #233 AND #234

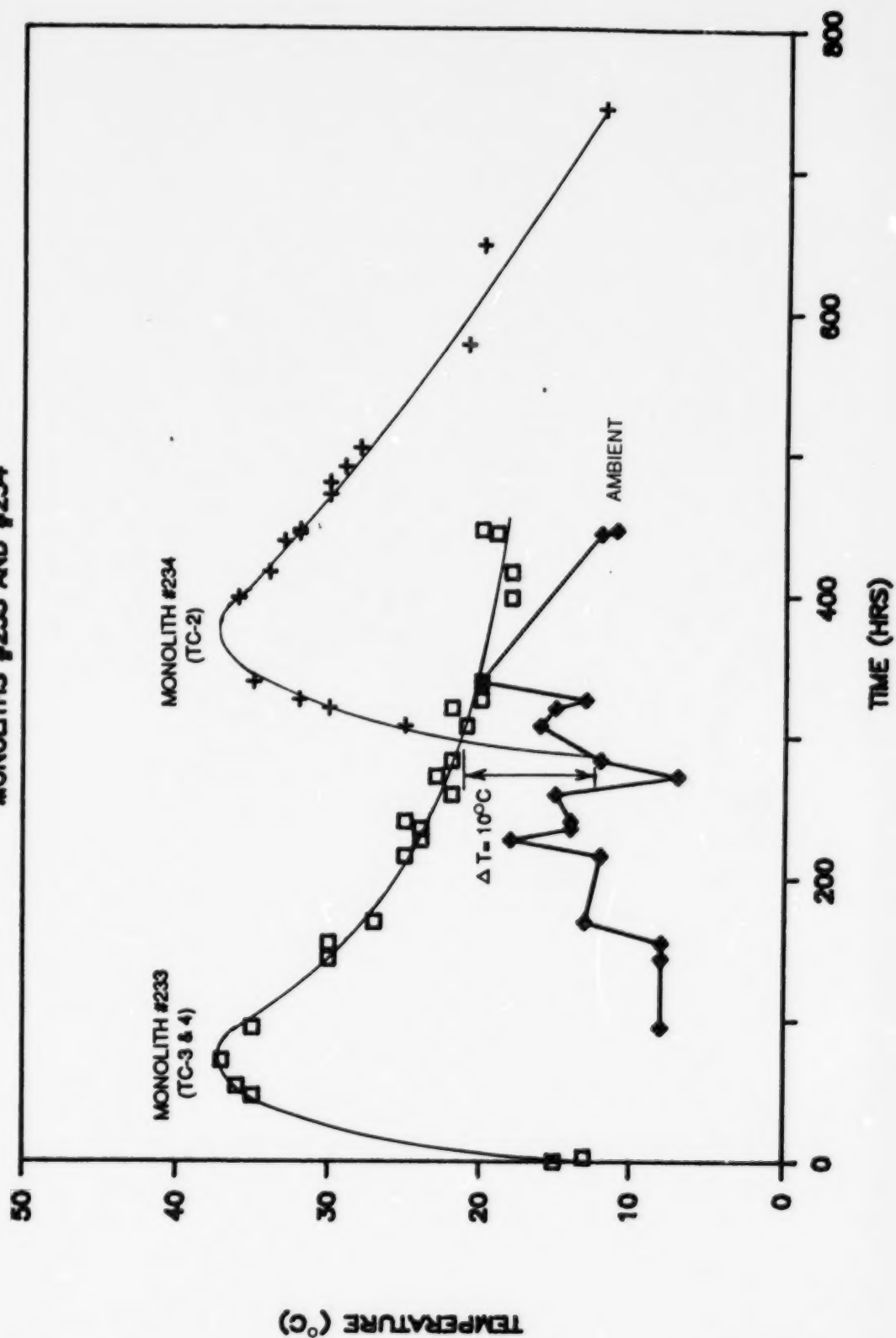


FIGURE 4

DISTRIBUTION

Mr. J.L. McFarlane	Darlington GS
Mr. W. Cushing	Darlington GS
Mr. J. Aitken	Darlington GS
Mr. G.A. Mentès	Civil Design, H17E27
Mr. J. Kenthol	Design & Development - Gen, H17A27
Mr. R.I. Chen	Design & Development - Gen, H17B27
Mr. J. Hrutka	Design & Development - Gen, H17F27
Mr. J.C. Lee	Darlington Engineering, H16A22
Mr. D. Kwong	AECL - Sheridan Park
Dr. T.W. Klym	Civil Research
Mr. G.S. Kellay	Civil Research
Mr. H. Caratin/J.R. MacPherson	Civil Research
Mr. P.K. Mukherjee	Civil Research

Public Reference Centre
Editorial Section (2)
Office Copies
Extra Copies